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Assessing modelling approaches in selected AQUACROSS case studies

Deliverable 7.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642317.

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With thanks to: Manuel Lago, Hugh McDonald, Lina Röschel (ECOLOGIC), Nadja Neuman (IGB)

Project coordination and editing provided by Ecologic Institute.

Manuscript completed in September, 2018

Document title	Assessing modelling approaches in selected case studies
Work Package	WP7
Document Type	Deliverable
Date	28 September 2018
Document Status	Final draft

Acknowledgments & Disclaimer

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 642317.

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List of abbreviations

AF	Assessment Framework
CICES	Common International Classification of Ecosystem Services
CS	Case study
EBM	Ecosystem-based management
EF	Ecosystem functions
ESS	Ecosystem services
GBI	Green and Blue Infrastructure
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
MSFD	Marine Strategy Framework Directive
SDM	Spatial Distribution Model
SPBTT	Science-Policy-Business Think Tank
WFD	Water Framework Directive

About AQUACROSS

Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies (AQUACROSS) aims to support EU efforts to protect aquatic biodiversity and ensure the provision of aquatic ecosystem services. Funded by Europe's Horizon 2020 research programme, AQUACROSS seeks to advance knowledge and application of ecosystem-based management (EBM) for aquatic ecosystems to support the timely achievement of the EU 2020 Biodiversity Strategy targets.

Aquatic ecosystems are rich in biodiversity and home to a diverse array of species and habitats, providing numerous economic and societal benefits to Europe. Many of these valuable ecosystems are at risk of being irreversibly damaged by human activities and pressures, including pollution, contamination, invasive species, overfishing and climate change. These pressures threaten the sustainability of these ecosystems, their provision of ecosystem services and ultimately human well-being.

AQUACROSS responds to pressing societal and economic needs, tackling policy challenges from an integrated perspective and adding value to the use of available knowledge. Through advancing science and knowledge; connecting science, policy and business; and supporting the achievement of EU and international biodiversity targets, AQUACROSS aims to improve ecosystem-based management of aquatic ecosystems across Europe.

The project consortium is made up of sixteen partners from across Europe and led by Ecologic Institute in Berlin, Germany.

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1 Background

This deliverable exemplifies how the modelling framework has been implemented in AQUACROSS case studies (D9.2) as part of the Assessment Framework (AF) to support sustainable ecosystem-based management (EBM). The modelling framework allows linking the ecological and socio-economic system through different modelling steps, reflecting the steps of the AF (Figure 1).

The ecological and socio-economic systems interact through the supply vs. demand of Ecosystem Services (ESS): while the supply reflects the capacity of the ecological system to fulfil social demands of ESS by Ecosystem Functioning (EF) (i.e., providing human welfare), it is the demand of ESS by the socio-economic system that may affect the structure and functioning of the ecological system (Gómez et al. 2017) (D3.2). Aquatic ecosystems are rich in biodiversity and habitats, providing numerous economic and societal benefits to humankind. Many of these valuable ecosystems are at risk of being irreversibly damaged by human activities. These pressures threaten the sustainability of these ecosystems, their provision of ESS and ultimately human well-being. Hence, the AQUACROSS Assessment Framework requires that this interaction is taken into account. This can be done retrospectively by using observed data and processes (i.e., analyse the past), or by analysing scenarios as potential future alternative management actions. The past is obviously constrained by the actions taken at a given time, therefore not giving much freedom to assess changes in management actions. Scenarios provide an alternative approach to asking the question of how the supply and demand sides could change, given a potential action strategy and its inherent boundaries. Here, modelling approaches are essential to (1) assess the status quo of the interplay between biodiversity, EF and ESS, and to (2) subsequently generate scenario projections of alternative management actions or environmental changes. Simultaneously, potential uncertainties stemming from the available data, tools and assumptions are to be assessed.

A total of eight AQUACROSS case studies defined different research questions aimed to showcase how the AQUACROSS Assessment Framework can be made operational supporting EBM by employing either quantitative spatially explicit modelling (i.e., CS2, CS3, CS5 and CS7) or qualitative non-spatial approaches (i.e., CS1, CS4, CS6 and CS8). The qualitative case studies linked the demand side of the system (i.e., social processes, drivers, primary human activities and the pressures they cause on the ecosystem) with the supply side of the system (i.e., ecosystem processes, EF and the ESS they supply, leading to benefits for society) using the linkage framework that is described in (Pletterbauer et al. 2017) and (Nogueira et al. 2017) (D4.1, D5.1). Following the Assessment Framework, management of biodiversity, ecosystem functions (EF) and ecosystem services (ESS) in a multiple-step workflow is required.

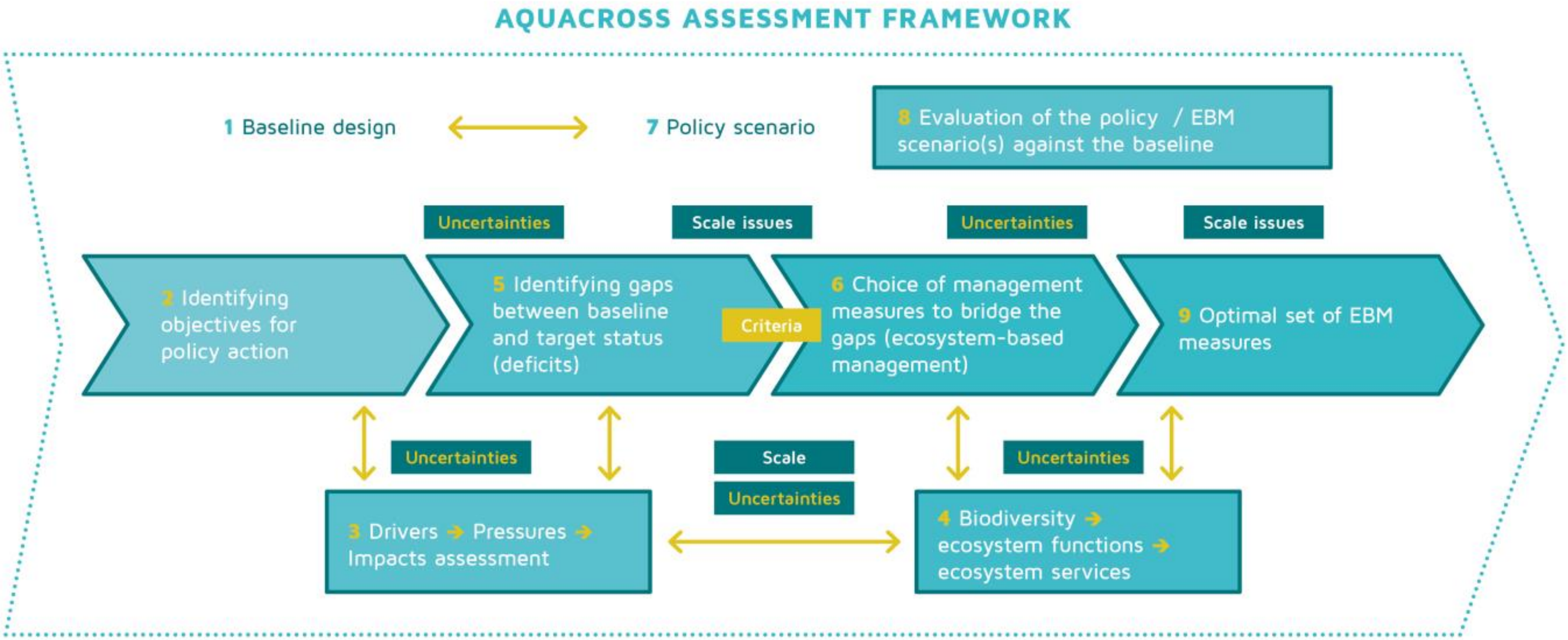

Figure 1: The AQUACROSS Assessment Framework sequence

This requires knowledge regarding (i) the spatial and temporal patterns of biodiversity, EF and ESS, i.e., how they are represented across the landscape and through time, (ii) the linkages of drivers and pressures between biodiversity, EF and ESS and how one mediates the other including feedback mechanisms, (iii) setting targets that balance to which degree biodiversity and other ESS can be achieved cost-efficiently. These targets function as scenarios in spatial modelling approaches. If applicable, (iv) a spatial planning approach can be applied to spatially prioritise management zones deemed suitable for biodiversity conservation, or that allow beneficiaries to carry out particular activities to capture ESS to various degrees. All elements run spatially-explicitly, allowing the pinpointing of locations and magnitude of overlap and dependency among the three components (i.e., BD models, ESS models and joint prioritisation) and any changes thereof.

In this deliverable, we present the implementation of the quantitative spatial modelling/planning approaches in selected case studies. We further assess the results of case studies regarding biodiversity and ESS to support EBM.

2 Introduction

2.1 Building on previous work in AQUACROSS

The AQUACROSS Assessment Framework describes a workflow of how the ecological and socio-economic systems can be linked, with the general goal to balance biodiversity and ESS supply and demand in aquatic ecosystems (Fig. 1). To make use of this framework, several requirements and prior steps need to be fulfilled and accomplished, respectively. Building on previous outcomes of AQUACROSS, this report illustrates the implementation of spatially explicit modelling approaches in selected AQUACROSS case studies. These quantitative modelling approaches support EBM by employing models at different spatial scales and different study areas. A first step is to identify the linkages between biodiversity and ESS, and the drivers and pressures within and among the ecological and socio-economic systems. The models hence build on the work of (Pletterbauer et al. 2017) (D4.1), (Costea et al. 2018) (D4.2), (Nogueira et al. 2016) (D5.1) and (Nogueira et al. 2018) (D5.2). These linkages are required to get an overview of the causal mechanisms and to identify the relevant factors that a given model should be taking into account (Domisch et al. 2017) (D7.1). The linkages hence provide the basis for (i) identifying changes in drivers and pressures, and (ii) to use these in the potential forecasting to test alternative management actions within aquatic ecosystems.

For this forecasting, the linkages can be applied in a qualitative or quantitative way. For instance, water abstraction for anthropogenic use might impact river discharge patterns, potentially impacting the aquatic biodiversity detrimentally. This link could be expressed as such in a qualitative way, e.g. through narrative, fuzzy cognitive mapping (CS4), or by other semi-quantitative models as described in the linkage framework; or in a quantitative way by specifying the detrimental impact on fish abundance or species richness in relation to the amount (or percentage) of water used. Furthermore, this information can be used in a spatially-explicit context (Domisch et al. 2017) (D7.1), when the location of water abstraction and occurrence of fish are known. Spatially-explicit models use the data on the spatial distribution of aquatic biodiversity and ecosystem services (e.g., clean water provision, flood protection, carbon storage, and recreational opportunities) to prioritise areas for biodiversity conservation and ecosystem service delivery, therewith securing the future access to these services, while minimising their impacts on aquatic ecosystems in selected case studies. Spatial prioritisation can be done for the current and future status and management targets across different aquatic ecosystem realms. The spatially-explicit modelling workflow is explained in detail in (Domisch et al. 2017) (D7.1) and outlined in Figure 2.

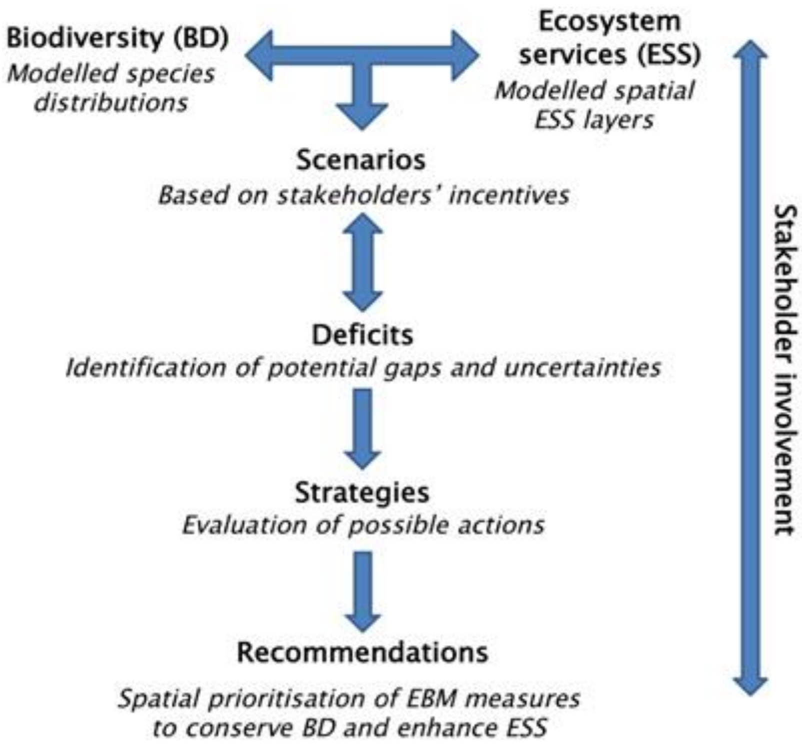

Figure 2 Simplified workflow of the spatial modelling approach in AQUACROSS. In this deliverable, scenarios are defined by stakeholder needs and e.g. represent alternative management scenarios or consider external scenarios such as climate or land use change.

In short, the range-wide habitat suitability of e.g. a number of fish species can be modelled and used as a surrogate for the aquatic biodiversity in the study area. The result of this biodiversity model is a map indicating the probability of occurrence of these fish species, dependent on the linkages specified by the drivers and pressures. The defined management goal may be to balance biodiversity and ESS, hence the range-wide ESS features have to be collected or modelled as well (for instance, carbon storage supply, or water use demand). The result of the ESS model is a suite of ESS supply and demand layers. The spatially-explicit biodiversity and ESS information can then be used to prioritise suitable areas for either conservation or ESS supply and demand, given specific management targets. A question could be, for instance, where in the study area should (i) a management area for biodiversity be allocated to cover 20% of the current fish habitat, while simultaneously enabling at least 50% of the current carbon storage supply and water abstraction demand, while moreover granting access to areas deemed attractive to enable 30% of the recreation demand? Additionally, questions of cost-efficiency can be covered. Such complex balances can be planned with spatial prioritisation analyses that enable multi-zoning within a study area (Hermoso et al. 2018), while taking stakeholder requirements into account (Langhans et al. 2018). The final outcome of these analyses are maps that depict biodiversity conservation and ESS supply and delivery areas.

2.2 Spatially-explicit modelling in selected case studies

Four of eight case studies opted to follow non-spatial modelling approaches due to different research questions, data, or approaches (i.e., CS1, CS4, CS6 and CS8), as explained in D7.1 to fulfil the scope of the AQUACROSS project, i.e. EBM for the protection of aquatic biodiversity. Another four case studies (i.e., CS2, CS3, CS5 and CS7) employed quantitative spatially explicit modelling approaches. In this report, we focus on the case studies which followed the suggested spatially-explicit modelling approaches to test their applicability in supporting EBM. This report thus summarises the core results towards achieving the biodiversity and ESS balance in their areas. We illustrate the spatially-explicit modelling approaches and their key outcomes within four AQUACROSS case studies: The Intercontinental Biosphere Reserve of the Mediterranean: Andalusia (Spain) - Morocco (CS2), the Danube River Basin (CS3), the Ria de Aveiro (CS5), and the Swiss Plateau (CS7). All these case studies propose an approach that allows to show ecological and societal requirements as part of an integrated management plan considering biodiversity, ESS and potential spatial prioritisation. The presented case studies provide spatial maps and demonstrate how emphasizing various biodiversity or ESS targets in an EBM framework can be used to test various spatially explicit management options across different spatial scales. The non-spatial modelling approaches (i.e., CS1, CS4 and CS6) are covered in detail in Deliverable 8.2.

To introduce the spatially-explicit modelling approaches used, we first provide a short overview of each case study along the case study-specific workflow. As introduced in (Domisch et al. 2017) (D7.1) and due to the high heterogeneity among case studies, a single spatially-explicit modelling approach was deemed not suitable. Rather, each case study is required to use a model approach that is capable to capture essential signals in biodiversity and ESS depending on the data availability and quality, and the appropriate spatial and temporal scale. Moreover, due to the importance of assessing relevant drivers and pressures across aquatic realms, different modelling approaches were used to evaluate suitable indicators (Pletterbauer et al. 2016; Domisch et al. 2017) (D4.1, D7.1). Also different model components were used to spatially prioritise biodiversity, EF and ESS (chapter 3.4).

The different modelling approaches and the data provided in case studies allow for the use of management scenarios (chapter 4) to assess and iterate how biodiversity, EF and ESS might be affected as a result of management actions (chapter 5). These steps are essential to provide advice and improve the knowledge about the potential consequences of management actions (i.e., setting targets for biodiversity conservation and allocation of ESS), and are considered key inputs for management decisions.

3 Modelling approaches and scenarios

3.1 General approach

The linkages between biodiversity and ESS can be analysed in a qualitative, quantitative, or spatially-explicit way. Each model type has its own advantages and limitations (Domisch et al., 2017) (D7.1). Obviously, the model choice depends on the aim of the study, on the available data, time and the effort required to build the model (i.e., for a quick analysis of linkage dependencies a qualitative model might be sufficient; however, it cannot be used to quantitatively assess alternative management actions spatially). We refer to (Costea et al. 2018.) (D4.2) and (Domisch et al. 2017) (D7.1) for a broad overview of the different modelling methods, and to the subsequent sections describing the modelling approaches in the individual case studies. In the next chapter, we outline the spatially-explicit modelling techniques of the four case studies. The spatial modelling framework consisting of three components (i.e., biodiversity models, ESS models and joint prioritisation), will be described in the following chapter.

The AQUACROSS case studies focus on understanding the effect of different water-related management strategies on ecosystems and biodiversity, or the social-ecological interactions (e.g., between tourism and recreational fishing, Table 1). AQUACROSS distinguishes between baseline and policy scenarios (see Martin et al., 2017) (D7.2). A baseline scenario is a shared view of current trends and vulnerabilities in ESS and biodiversity and associated challenges in a case study. Often, the case studies comparatively analyse management strategies to understand trade-offs or which choice might be most cost-efficient. The alternative scenarios focus on potential solutions and can represent alternative pathways for reaching a target (normative) or represent and assess the outcomes of several alternative policy instruments or measures (descriptive).

Table 1 Model types and research objectives in selected AQUACROSS case studies that worked on spatially/temporally explicit models, outcomes are spatially explicit.

Case study	Model type / framework	Research objective
Andalusia-Morocco (CS2)	Biodiversity modelling (SDM) ESS modelling (ARIES) Marxan with Zones	Decision support for policy processes to identify a suite of potential locations for a multifunctional GBI. Target definition with stakeholders ongoing.
Danube (CS3)	Bayesian Networks ESS modelling (ARIES)	Hydromorphological alterations and their effects on ecological status. Conserve a) biodiversity (birds) in Danube delta and, b) biodiversity (fish, inverts) in tributaries, c)

		biodiversity in protected areas along the navigable stretch of the Danube River. Targets derived from WFD and Biodiversity strategy.
Ria de Aveiro (CS5)	Spatial multi-criteria analysis ESS modelling (ARIES)	Management of Natura 2000 areas from freshwater to coastal waters focused on EBM measures.
Switzerland (CS7)	1. Ecological trait-based species distribution model for macroinvertebrates 2. Complementing reach scale assessment with spatial criteria to get catchment scale ecological assessment that can be used for spatial prioritization of rehabilitation measures	1. Quantifying the impact of different natural and anthropogenic influence factors on the occurrence of macroinvertebrates in rivers 2. Improving the ecological state of rivers in the Swiss plateau while taking into account costs of management measures and ESS trade-offs and including external input scenarios for considering future changes in boundary conditions such as socio-economic development and climate change.

The AQUACROSS case studies aimed to identify drivers and pressures defined in Task 4.2, across the freshwater, coastal and marine realms, and assessed potential impacts on biodiversity and its capacity to support ESS (D5.2). Each case study utilised broad activity types and pressure categories to standardise their approach during the AQUACROSS project (Pletterbauer et al. 2016) (D4.1). Different ESS, including provisioning and cultural services and their use, were considered and evaluated to reach an understanding of how sustainability can be achieved and thus to support EBM (Gómez et al. 2017) (D3.2). As a participatory valuation of ESS offers an integrative perspective for EBM (Lillebo et al. 2015, 2016; Dolbeth et al. 2016), stakeholders' activities, their needs, and prioritised ESS were considered during the analyses to account for the demand side. Accounting for the demand side is necessary, as it ultimately drives the activities that enforce the pressures over the aquatic ecosystems (Pletterbauer et al. 2016) (D4.1, D9.2).

Four case studies (Figure 3) were selected showcasing different spatial modelling approaches. They cover freshwater, coastal and marine ecosystems, use different modelling techniques and individually defined potential scenarios based on stakeholders' elicitations to fulfil objectives of the EU Biodiversity Strategy to 2020. Similarly, they aim to identify potential areas of interest for conservation or restoration measures, but also areas where ESS supply and demand are provided.

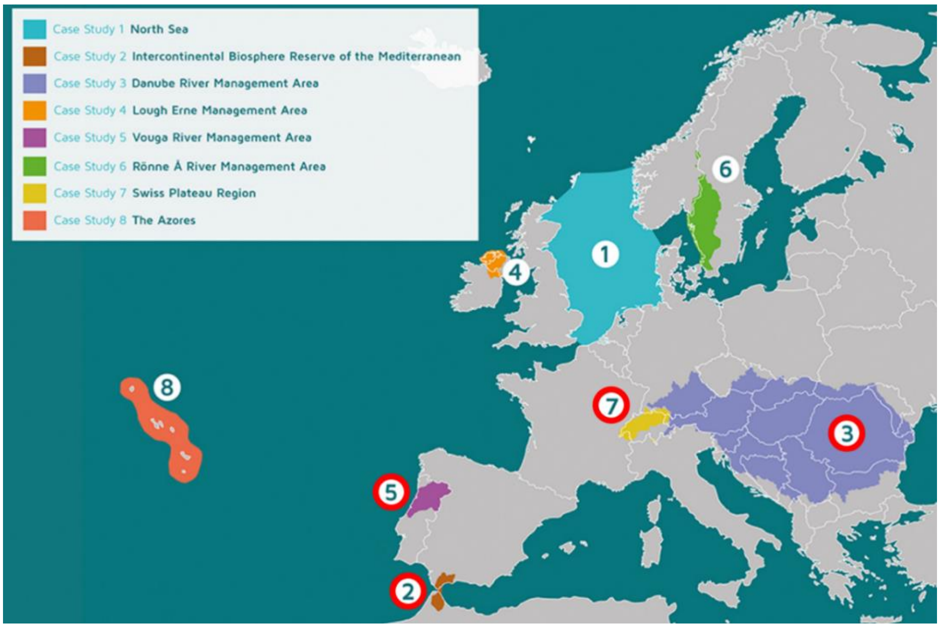

Figure 3 Location of four selected case studies in this deliverable: (CS2) Andalusia, (CS3) Danube, (CS5) Ria de Aveiro, and (CS7) Switzerland.

3.2 Andalusia Morocco (CS2)

CS2 followed the modelling framework proposed in (Domisch et al. 2017) (D7.1). The case study aimed at identifying a suite of potential locations for multi-functional Green and Blue Infrastructure (GBI) designation, delivering an outcome that balances biodiversity, EF and ESS in Andalusia (Spain) and Morocco. The GBI is a strategic policy instrument to provide spatial areas with multiple potential features and benefits that deliver multiple ESS such as recreational opportunities, water purification and food production (European Commission – DG Environment 2012). CS2 aimed to explore different alternatives for designing GBI (Figure 4) that maximizes the multi-functionality of spatial units with minimum costs, while meeting the targets of the EU 2020 Biodiversity Strategy; namely, enhancing biodiversity, ESS, and restoration of degraded ecosystems.

Following the Common International Classification of ESS (CICES) (Chan et al. 2006; Haines-Young 2016; Hermoso et al. 2018), 15 ESS were mapped in ARIES (Willcock et al. 2018) and presented as an averaged value through the ecosystem capacity to provide services derived from the SES supply matrix (Teixeira et al. 2018), re-scaled to range between 0-1. For biodiversity, the potential spatial distribution of three freshwater fish, six invertebrate species, 16 aquatic birds, three amphibians and 13 characteristic plant species were modelled and quantified as a probability ranging between 0-1 using Species Distribution Models (SDMs). The SDMs relate species occurrences to the environmental conditions such as mean annual air temperature, mean current velocity and bathymetry. All of these data were used in Marxan with Zones (Watts et al. 2009) to prioritise the spatial allocation of GBI to enhance the maintenance of multiple ESS while co-benefiting as much as possible biodiversity conservation.

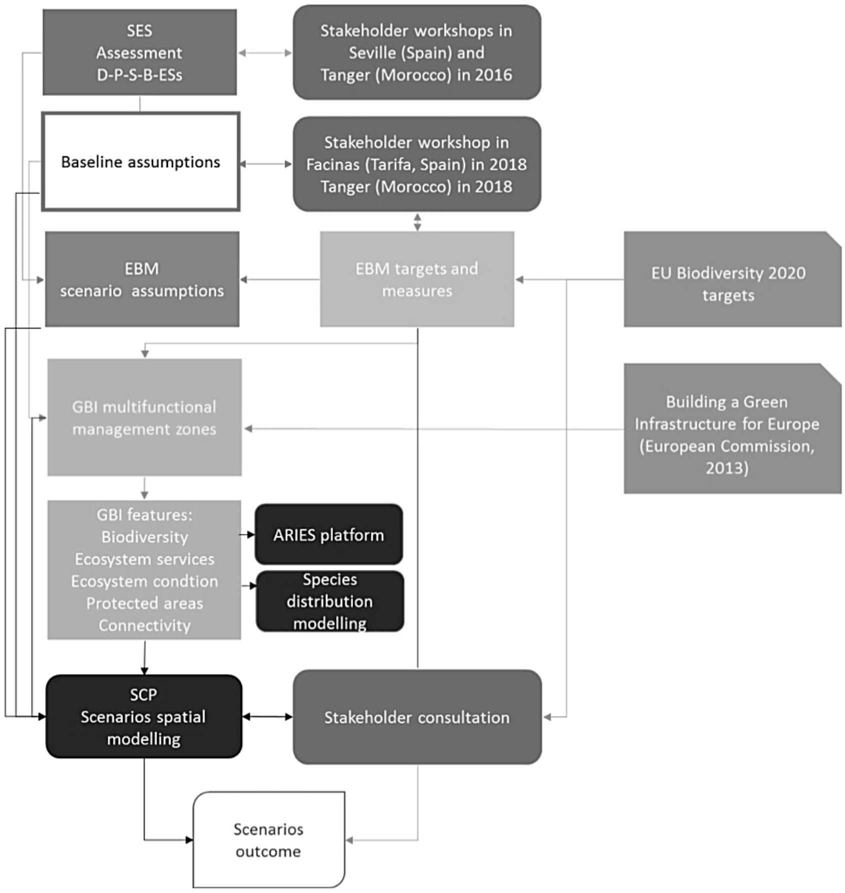

Figure 4 The workflow scheme of Andalusian-Moroccan case study

CS2 analysed the outcome of two different scenarios: (1) a baseline-scenario that considers the current status and distribution of biodiversity and ES in the CS2 area, and (2) a second GBI design incorporating the restoration of degraded habitats using the EBM approach to reach the EU biodiversity strategy targets (European Commission 2011). Potential targets for biodiversity and ESS were to protect more than 25% of the threatened species and restore at least 15% of degraded ecosystems. The former allowed identifying priority areas, additional to those already existing, that are needed to fill the gaps in coverage of threatened species and the latter allowed assessing where restoration measures would most benefit the design of GBI network.

With regards to both the baseline and restoration scenarios, the best solution for GBI designation were largely achieved with the lowest cost (i.e. the ratio between the amount of the conservation feature held in each management zone and the particular zone target was larger than 1, Figure 5). This study allowed a separate view on different realms analysed. In the freshwater realm, relatively high probability of conflicts between conservation and exploitation goals is expected, while fewer conflicts are expected in the marine and coastal areas.

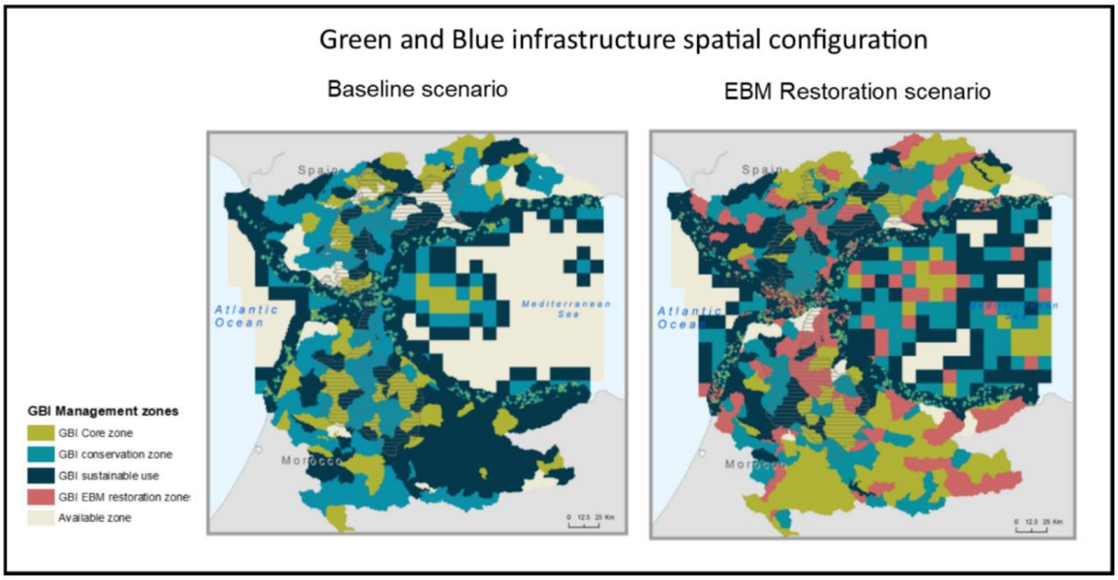

Figure 5 Spatial configuration of the GBI in baseline and the EBM scenarios

This study showed key areas for potential enhancement of ecosystem services and how EBM restoration measures can be explicitly included in an optimal spatial planning of a GBI.

3.3 Danube (CS3)

CS3 assessed biodiversity and ESS in the navigable main stem of the Danube River and its floodplains. Currently, the reduction of lateral connectivity and exchange processes between the main river channel and floodplain areas due to channelization has caused significant hydromorphological alteration in the Danube River Basin. This study aimed to spatially prioritize potential river-floodplain areas for conservation and restoration management to maximise multi-functionality related to biodiversity and ESS (Figure 6). The goal was to conserve the remaining semi-natural areas and ensure reversibility to natural conditions related to multiple human activities.

The relationship between status indicators (i.e., biodiversity and ESS), pressure indicators (i.e., hydromorphological alterations), and underlying drivers (i.e., land-use, hydropower and navigation data) were modelled and predicted. For biodiversity modelling, a Bayesian network approach was used to consider linkages between multiple environmental drivers. Eleven widely distributed species across four taxonomic groups (i.e. six fish, two amphibians, two birds and one mammal species) were selected to represent biodiversity. These species are represented in at least 60% of the sites situated along the Danube and are sensitive to the hydromorphological pressure variables.

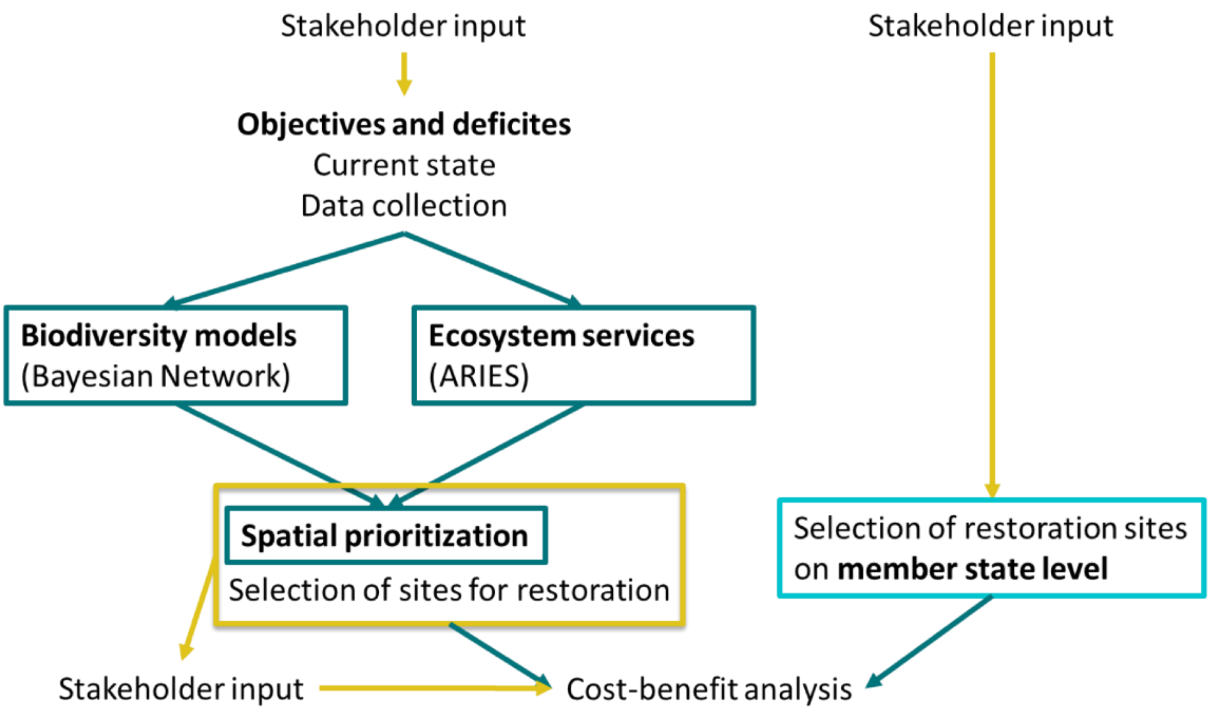

Figure 6 The workflow scheme of Danube case study. The approaches on the left-hand side prioritise restoration sites at the Danube level.

Three ESS (i.e., flood regulation, crop pollination, and recreational potential) were modelled and quantified using the ARIES modelling platform (Willcock et al., 2018). Taking the remaining multi-functional areas as well as areas with potentially restorable multi-functionality and availability of remaining semi-natural area for restoration into account, a trade-off analysis identified important areas with biodiversity and ESS conservation and restoration potential. A cluster analysis was used to identify groups of river-floodplain reaches with homogenous sets of species and levels of ecosystem service provision.

A baseline scenario represents the sites already proposed or planned for restoration along the Danube main stem. Future scenarios are related to three criteria of multi-functionality, reversibility and semi-natural area. The scenarios are weighted ranging from scenario one to scenario five. Scenario one prioritises river reaches according to their degree of multi-functionality and the availability of semi-natural areas (i.e., most possible preservation of agricultural areas). Scenario five prioritises river reaches according to their degree of multi-functionality and reversibility to natural conditions related to multiple drivers (i.e., prioritisation of reaches with low constrains from multiple drivers).

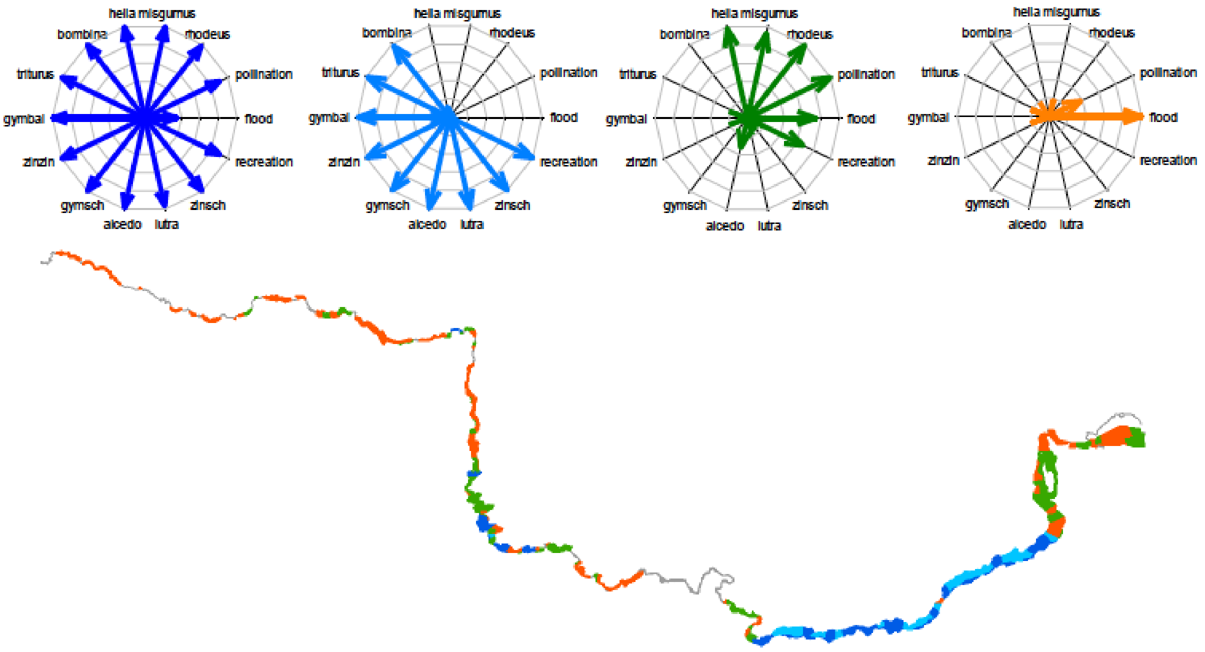

Figure 7 Cluster analysis results, showing four relevant clusters related to biodiversity and ESS values. Arrow length represents the relative value across the clusters, and longer arrows show higher potential of biodiversity and ESS in the respective cluster. Dark blue (cluster 1): multi-functional cluster; light blue (cluster 2): rheophilic/river and recreation cluster; green (cluster 3): stagnophilic/floodplain species and multiple ESS cluster; orange (cluster 4): reduced multi-functionality with remaining high flood regulation potential cluster. Color codes show the distance from ideal point for conservation and restoration, ranging from dark blue (relatively close to the ideal conditions, with high priority for restoration) to red (highest distance to ideal conditions, with low priority for restoration).

Spatially prioritised areas were selected according to the biodiversity and ESS models. Areas with high restoration potential are scarce along the Upper Danube (Figure 7, clusters 2 and 3), thus the reversibility criterion declines the number of prioritized areas for restoration. Reconnection is an effective restoration measure in this region as it increases the multi-functionality of river reaches. According to the semi-natural area criterion, the Middle Danube region includes the highest proportion of prioritised reaches with a low distance to the semi-natural area. However, according to the reversibility criterion, prioritised reaches with high restoration potentials (hydromorphological alteration is 100% reversible) are found to be along the Lower Danube region (Funk et al., submitted). The trade-off analysis enabled the identification and systematic prioritisation of high value river-floodplain reaches with multi-functionality that should be considered for conservation. The approach of coupling statistical models with spatial prioritisation is a promising tool that highly supports catchment-scale management plans.

3.4 Ria de Aveiro (CS5)

CS5 investigated biodiversity and ESS changes in relation to spatial flows (biotic and abiotic) and how they affect ecosystem resilience in the Baixo Vouga Lagunar region (Figure 8). Implication of changes in hydrological conditions due to floodbank extension on associated ESS was modelled. CS5 assessed the trade-offs between conservation measures and different ESS together with relevant stakeholders.

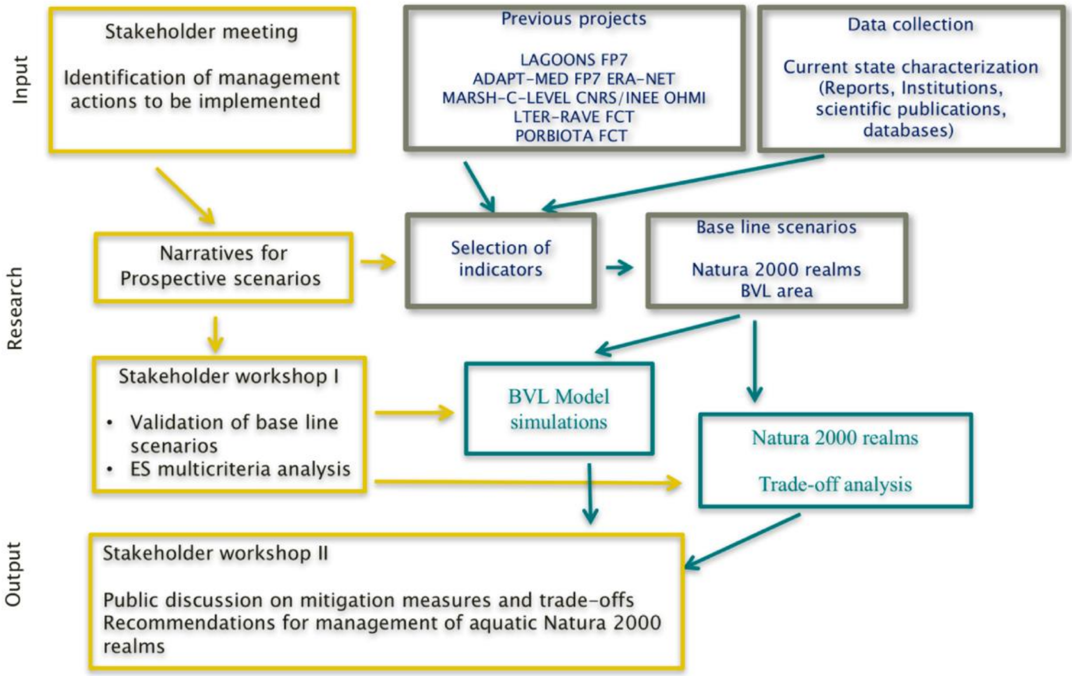

Figure 8 The Workflow scheme of Ria de Aveiro case study

This study aimed to improve saltmarsh habitat for four representative plant species of mid-high marsh halophyte communities and 10 associated ESS such as biotic-based energy sources, nutritional abiotic substances, maintenance of physical chemical biological conditions, and physical and intellectual interactions with biota. To characterise and assess potential losses of ESS of interest (based on stakeholders' opinion) that are associated with biodiversity, ESS were used as input to a spatial multi-criteria analysis. This identified potentially best management actions to compensate for the predicted loss of biodiversity and ESS in the Natura 2000 protected area of Baixo Vouga Lagunar for both upstream and downstream of the floodbank. This sectorial and site-specific management approach might contribute to establishing prospective scenarios for changes in ESS provision and to implementing EBM practices at regional scale.

The traditional agricultural mosaic fields with woodland elements, the freshwater courses and the sub-tidal mosaic fields are found to be the main areas to be preserved in Baixo Vouga Lagunar (Martínez-López et al. submitted). The floodbank extension results in counteracting the negative impacts of estuarine channel dredging and desanding such as salt water intruding on agricultural fields and freshwater courses. The priority habitats in the Ria de Aveiro are thus well aligned (i.e. effectively protected) with the latest interventions (e.g., floodbank extension) that are recently implemented and/or planned for the near future in this area.

3.5 Swiss Plateau (CS7)

In CS7 an approach based on decision support methods was presented. It aggregates local (i.e., sampling site) and reach-scale (i.e., short river segment) ecological assessments in river ecosystems to describe the ecological state of entire catchments (Figure 9, Kuemmerlen et al., 2018). At the reach-scale, the ecological assessment is based on the morphological, nutrient and micropollutant states of the water body. The assessed ecological states for all reaches are then aggregated using an objective’s hierarchy and five spatial ecological criteria to obtain the ecological assessment at the catchment scale. This study developed, tested and recommended a specific set of spatial criteria that represents ecological concepts such as migration potential, resilience and habitat diversity in a spatially explicit way. It aimed to explore potential applications to support long-term planning for spatial prioritisation of restoration measures.

Aggregating reach-scale ecological assessments based on morphological, nutrient and micropollutant states and considering important ecological principles enables comparing of the ecological value of different spatial arrangements of river reaches and supports prioritisation of restoration as well as conservation planning. Furthermore, the so-called catchment scale assessment will support river managers to increase the efficiency of management strategies. This data prepares the basis for diverse analyses, such as the evaluation of management scenarios. In addition, an ecological trait-based species distribution model was developed to assess the effect of different human activities on the distribution and diversity of macroinvertebrates in Swiss rivers (Vermeiren et al., in prep 1, Vermeiren et al., in prep 2). It highlights the need for a coordination of management actions to stop the biodiversity loss in the Swiss Plateau.

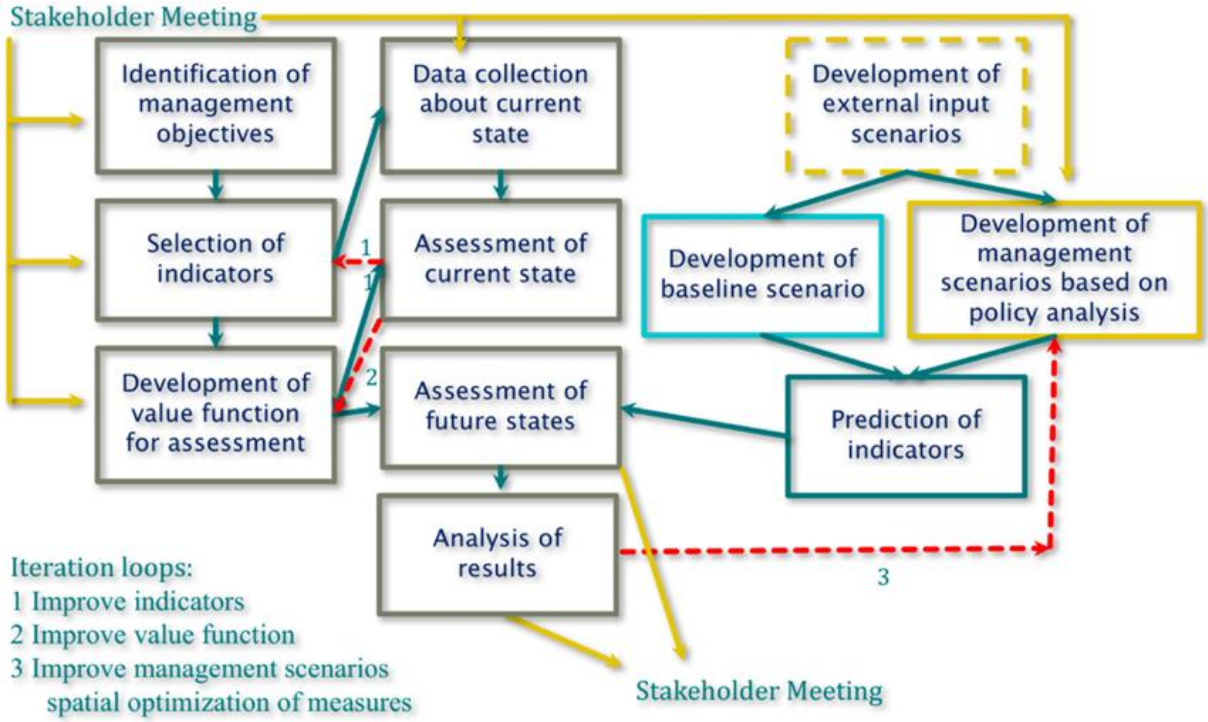

Figure 9 The workflow scheme of the Swiss case study

4 Synthesis

4.1 Case studies

All four AQUACROSS case studies presented in this deliverable used spatial modelling approaches. They all addressed the challenge to balance requirements for biodiversity conservation and provisioning of other ESS as crucial components to be considered in decision-making. Three case studies (i.e., 2, 3 and 5) modelled explicitly spatial patterns in biodiversity and ESS.

The Andalusian-Moroccan case study (i.e., CS2) suggests solutions for three aquatic realms (i.e., freshwater, coastal and marine) by developing direct recommendations for GBI designation for the management and planning of transboundary aquatic ecosystems within natural protected areas. The case study identified major drivers and pressures such as different demands that lead to different transnational management and planning strategies, and transboundary fragmentation of water bodies and habitats. This case study extended spatial models and provided a GBI designation that identifies the locations, where nature-based solutions could be more likely to succeed and maximise the delivery of ecological benefits.

The Danube case study (i.e., CS3) used biodiversity and ESS data as well as floodplain characteristics and status of protected areas (Natura 2000 sites) and modelled potential future development of aquatic ecosystems under management schemes. These forecasting models allowed CS3 to prioritise sites for habitat restoration to counteract the negative biodiversity impact of hydromorphological changes (e.g., navigation, land use change, and hydropower development) as one of several significant water management issues affecting Danube's biodiversity and associated ESS.

The Ria de Aveiro case study (i.e., CS5) analysed EBM measures in aquatic (freshwater, transitional, and coastal) Natura 2000 catchment and coastal sites. The case study developed innovative management instruments by engaging stakeholders to set out conservation objectives for biodiversity and preservation of ESS, and restoration measures for Natura 2000 sites. It evaluates the impact of the main drivers and pressures such as salt-water intrusion due to dredging for the harbour in the Ria de Aveiro area.

The Swiss plateau case study (i.e., CS7), evaluated the ecological state of river ecosystem at large scales while taking into account potential costs of restoration measures and ESS trade-offs. This was done by aggregating reach-scale ecological assessments in river ecosystems and describing the ecological state of entire catchments. The study estimates the benefits from different management strategies (including diverse management alternatives) and thus, formulating the societal preferences, allows ranking the different management alternatives.

Experts and stakeholders were intensively involved in all four case studies in order to evaluate aquatic biodiversity links to ESS, and to include stakeholder needs in the modelling approach. Furthermore, both biologically mediated ESS and those reliant on purely physical aspects of the ecosystem were considered in case studies, since both have implications for spatial planning, management and decision-making. All case studies explored potential applications of the ecosystem-based management concept to support long-term planning for spatial prioritisation of conservation and restoration measures. Moreover, all case studies prepared the necessary data that might be used as foundation for forecasting, once external policy and management scenarios become available.

4.2 Biodiversity ~ ESS balance

Linking the ecological and socio-economic systems is the major aim of a sustainable EBM plan, as these two systems interact through the supply versus demand of ESS (Gómez et al. 2017) (D3.2). This requires stakeholders' involvement – e.g. to set targets, among other input – prior to analysing and modelling spatial patterns of biodiversity and ESS in a study area. The selected AQUACROSS case studies aim to develop and use management tools and concepts such as indicators, maps, ecosystem assessments and participatory approaches. They further develop mechanisms for promoting the delivery of ESS.

Assessing a combination of these components in AQUACROSS case studies allowed to test key causal links between biodiversity and ESS and to forecast future conditions. It further identified an overview of potential changes considering the linkages and interactions between biodiversity and other ESS. Furthermore, jointly assessing the dependency of biodiversity and ESS using a spatially-explicit modelling framework has yet rarely been investigated. The spatial modelling framework consisting of three components (i.e., biodiversity models, ESS models and joint prioritisation) allowed pinpointing specific patterns across the respective study areas, specifying priority areas for conservation of aquatic biodiversity and different ESS through restoration and/or management alternatives. Trade-offs between benefits from ESS against biodiversity and conservation goals were discussed. Therefore, jointly evaluating biodiversity and ESS considering stakeholder needs allowed identifying areas with multi-functional opportunities (case study 2, 3 and 5), which might be seen as business solutions and innovative processes that balance environmental health and human well-being.

(Domisch et al. submitted) is another good example for spatial prioritisation maps depicting biodiversity conservation and ESS delivery areas within the transboundary Danube River Basin (Figure 10). The model-coupling process consists of quantifying the current spatial representation of biodiversity (using SDMs) and ESS (using ARIES, Villa et al., 2014), followed by setting management targets for distinct management zones. A spatial prioritisation approach allocates management zones across the study area and minimises the associated costs while fulfilling biodiversity and ESS targets. Spatial maps clarify differences in the spatial configuration of management zones and would provide a platform to foster discussions and facilitate agreements among stakeholders. Such spatial maps are vital to communicate biodiversity and ESS targets regarding effectiveness, efficiency and social equity in any area of interest. Such spatial prioritisation map for EBM is provided by all the selected case studies described in this Deliverable.

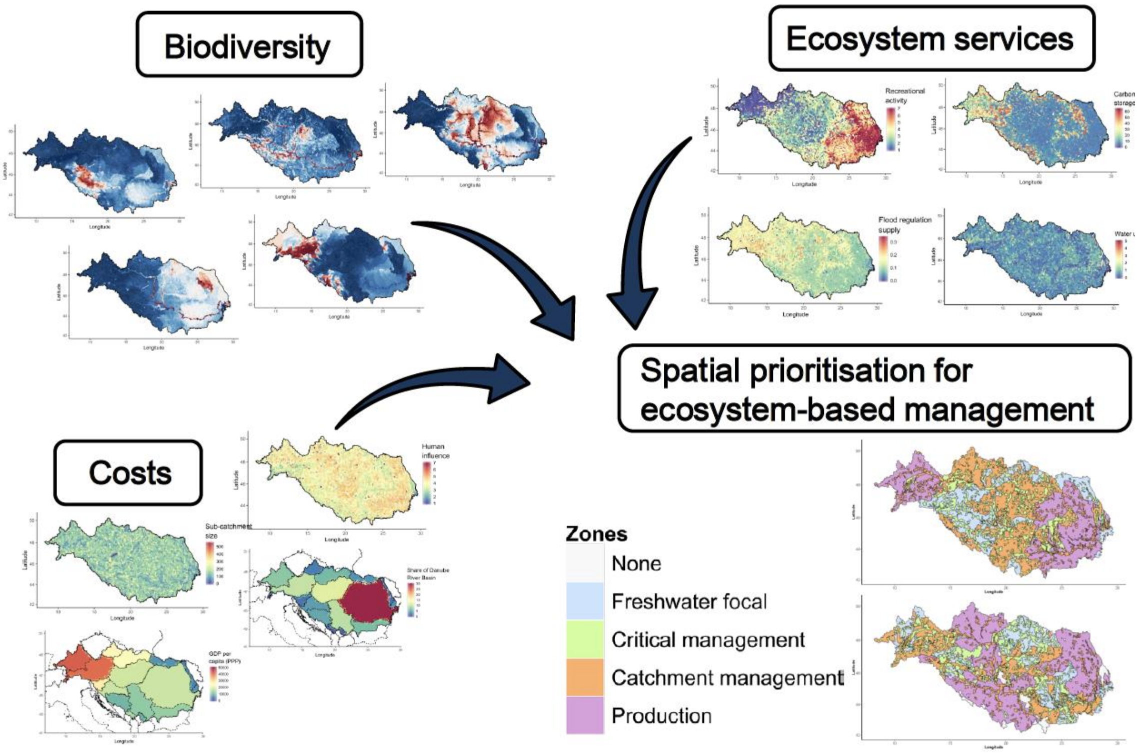

Figure 10 Spatial maps of biodiversity (species distribution, upper left), ESS layers used in the model-coupling framework (upper right), and cost layers used in Marxan with Zones (lower left), which resulted in spatial prioritisation for EBM in Danube catchment (lower right) (Domisch et al., submitted)

4.3 New insights and recommendations

The selected modelling approaches developed in AQUACROSS case studies are suitable to be further applied in other regions. Model results can be used to support management decisions regarding different, potentially (at least partly) conflicting policy goals (e.g. Biodiversity Strategy, WFD, MSFD, the Renewable Energy Directives) and human activities (Rouillard et al. 2016). Similarly, policy makers, investors and local communities as different stakeholders may all be interested in a balanced solution considering both biodiversity and ESS objectives but with very different individual preferences. The methods applied here provide maps to visualise potential outcomes of scenarios to stakeholders. The modelling outputs then enhance transparency and facilitate the decision-making processes with identification of critical areas that potentially need to be prioritized for allocating particular management actions. All these steps help to concurrently achieve conservation and socio-economic targets, which is in agreement with the EBM principles. This potentially leads to win-win situations that enhances biodiversity and concurrently allows ESS use, satisfying different stakeholder demands.

Evaluating ESS according to the output of ESS models would reduce the artifact of expert valuations system (Bagstad et al. 2013), and provide better estimates and accountability of services provision and their relative importance (Martínez-López et al. submitted).

Stakeholder involvement is a key part of the systematic conservation planning process (Watts et al. 2009), and is also important in the EBM process to, for example, define targets or make decisions about management scenarios. AQUACROSS case studies facilitated participatory processes involving stakeholders and decision makers across their respective study area and allowed capturing honest and reliable preferences regarding conservation and management goals (CS 3 and 5; Funk et al., submitted; Martínez-López et al. submitted; Lepetu 2012; Villamor et al. 2014). Identifying a suite of potential locations with multiple potential features and benefits based on stakeholder elicitation is highly recommended as it reduces conflicts and trade-offs between biodiversity and societal services, e.g. hydropower generation as shown in CS6.

Interestingly, the AQUACROSS case studies that tested spatial prioritisation were all large-scale studies, but also provide spatial prioritization as small scales. Small scale studies can also benefit from spatial prioritisation, if respective data is available, e.g. prioritising small Marine Protected Area locations around Faial and Pico islands in the Azores (D9.2).

4.4 Limitations

A number of limitations in their approaches have been identified by the case studies, which are related to data availability, connectivity, scenarios, socio-economic issues, and stakeholder involvement.

A prerequisite to apply the introduced modelling approaches in any region of interest is available data on all aspects under investigation (i.e., drivers, pressures, biodiversity, ESS). While the case studies used best available data on biodiversity, ESS and relevant drivers of pressure, data availability was identified as a limit by all case studies. For example, despite strong correlations between spatial criteria and biotic indices in assessing the ecological state of rivers in the Swiss plateau (CS7), more relevant data would increase the ability to successfully capture the target ecological processes and functions. Likewise, modeling of species distribution patterns in CS7 was conducted in relation to direct environmental and human influence factors. Nonetheless, the absence of widespread data on some of these direct influence factors necessitated their deprival from indirect influence factors, thereby increasing uncertainty in model input data (Vermeiren et al., in prep 1). The AQUACROSS case studies support similar findings from the literature that report detailed data in the freshwater realm on e.g. upstream and downstream movements of different species at different life stages, that might enable to estimate actual connectivity in the stream network (Calles and Greenberg, 2009). Furthermore, the niche breadth and dispersal ability of species (e.g. Heino, 2013), or direct monitoring of certain ecological functions such as leaf-litter breakdown in rivers (Gessner and Chauvet 2002) can be applied in statistical analysis to improve the modelling approaches. This has not been applied in our studies as investigations on collecting such data are rather scarce and dispersed, but first attempts to quantify equivalent ecological functions are underway.

Further improvements in spatial prioritisation might be expected if connections along the river network or between rivers and lakes within river basins are considered. This may better reflect crucial ecological habitats and ecosystem processes key to the maintenance of both freshwater biodiversity and ESS (e.g., refugia for migratory fish species) and may therefore allow better depiction of the influence on the ecological and physico-chemical state of downstream river reaches (e.g., Hermoso et al. 2011, 2012 and 2018). These connections are often little considered in spatial prioritisation within catchments, but were included in e.g. CS7 (Kuemmerlen et al., 2018).

In AQUACROSS case studies, scenarios are defined by stakeholder needs and e.g. represent alternative management scenarios or consider external scenarios such as climate or land use change (Martin et al. 2017) (D7.2), which can have synergistic or antagonistic effects in addition to stakeholder needs. Scenarios allow asking the question of how the supply and demand sides could change given a potential action strategy within the case studies. Through considering policy options, management decisions can be informed by modelled scenarios and the impacts to biodiversity and ESS (Nogueira et al. 2016) (D5.1). In addition, it is possible to analyse these outcomes under external scenarios such as climate or land use change (Martin et al. 2017) (D7.2). Except CS7 that used population projections, external scenarios have not been used despite being one of the original goals of AQUACROSS project (see Gómez et al. 2017) (D3.2). In line with the objectives of the AQUACROSS project on exploring practical applications of the EBM concept to provide advice to local managers in the case studies the case study focus shifted to management scenarios. Furthermore, variable time steps were used in each case study considering the different management questions addressed.

When several countries or even continents are involved (e.g., CS2: Andalusia-Morocco, CS3: Danube), further complexity is added due to (1) different demands and conservation agendas (Barbosa et al. submitted), (2) data availability, data provisioning and heterogeneity in data quality, and (3) language barriers. This led to rather large scale, higher level targets in the respective case studies (rather than detailed management actions) with less spatial resolution. For example, heterogeneity of the environmental problems combined with heterogeneous socio-economic conditions and inconsistent legislation along the Danube river makes a comprehensive planning of restoration sites very challenging (Case study 3; Funk et al., submitted). Applying the same approach with the same policy objectives across large areas may need assignment of specific targets for different sections (e.g., from river basins to regional or even country-wide).

To elicit priorities by different stakeholder groups in relation to the existing ESS can be largely affected by the number of participants. A low number of participants compromise the identification of different opinions representative of the whole community (Langhans et al.

accepted). Furthermore, relying on a few representatives only might hinder establishment of management alternatives and measures that were selected based on wider public preferences. Therefore, efforts must be made to maximise stakeholder participation in order to make the outcome be representative of the whole community, and hence useful for either the modelling approaches or respective environmental managers (Langemeyer et al. 2018).

Several more general limitations of the spatial prioritisation approach require careful consideration when applying the method. Setting the adequate targets for biodiversity (usually a proportion of the total population to be protected, e.g. 60 %) and ESS (a proportion of the delivered ESS) is not a trivial task as it is difficult to judge what "meaningful" targets are and also to justify the choice of the target level. This is crucial in terms of trade-offs. For example, two conflicting objectives as it could be the case of provisioning of water and recreational uses/ biodiversity conservation. This issue is related to the stakeholder involvement. If we cannot meet high expectations for all objectives, stakeholders should lead and inform the prioritisation process by defining their objectives and targets.

Hence, usually a range of different targets are used to develop an idea of how the prioritised areas change. It is suggested to run a sensitivity analysis instead of sticking to one specific target number. In the optimization analysis itself, it is currently not possible to include upstream or downstream effects of management alternatives, i.e. downstream propagation of the effects of a management alternative implemented in a specific planning unit to neighbouring planning units. The spatial prioritisation tool used in CS2 and CS3 (Marxan with Zones) works on fixed scenarios where the spatial distribution of biodiversity features (e.g., freshwater species in these case studies) and ESS are pre-assessed through predictive models, for example. This limits the capacity to tackle more dynamic processes associated, for example, to global change or the implementation of restoration actions. Although there are examples of studies that integrate these dynamic processes in prioritisation exercises by using Marxan (Bush et al. 2014; Langhans et al. 2014), these are limited in terms of the number and complexity of management alternatives that can be considered. For example, (Langhans et al. 2014) could only evaluate one restoration action at a time. The prioritisation of management actions individually limits the efficiency of solutions when multiple management actions are necessary, as co-benefits of multiple actions cannot be assessed (e.g., the implementation of two restoration action in a site might have synergistic effects and then boost the efficiency of our investment). Therefore, ideally multiple management alternatives should be considered simultaneously, so an optimal combination of all of them could be proposed so as to maximise return on investment. The limitation in terms of addressing multiple management options at the same time can be partially addressed in Marxan with Zones, through the consideration of multiple management zones, each of which could convey a different restoration option, for example (as proposed Langhans et al. in press). This new framework could also account for synergistic effects of different management options (e.g., by considering a management zone where two different actions would be implemented, rather than single management action zones). This alternative, however, is also limited by the number of different management zones that can be spatially prioritised. For example, a simple management plan exploring the spatial prioritisation of three EBM actions would need at least the consideration of seven zones (one of each management actions, three for the pairwise combination of them and an additional one for the full combination). Alternative options to overcome the limitations of available tools it would be the use of customised optimisation tools that allow assessing the cost-benefits of multiple management options in a dynamic (rather than static-based as mentioned above). For example, (Hermoso et al. 2015) developed a multi-objective optimisation algorithm that integrated predictive models in the prioritisation process, so management options could iteratively be assessed and prioritised, escaping from the limitation of static-based approaches.

Furthermore, cost-effectiveness is usually based on only rudimentary cost information and therefore has to be assessed with care. Last but not least, in case the case study area is large, only high-level decision makers and stakeholders are usually part of the process as including local stakeholders is perceived as too time-consuming.

5 Outlook

The spatial approaches used in the selected AQUACROSS four case studies enabled forecasting of priority multi-functional areas considering management alternatives. The case studies provided the foundation (i.e., methodology and data) required for forecasting optimal future conditions. A number of recommendations for future research were identified. The species distribution models used in case studies showed potential probability of presences only. Therefore, models did not explicitly account for inter-specific interactions (e.g., CS5; Martínez-López et al. submitted) or dispersal which are both thought to significantly improve the current models (Martínez-López et al. 2015; Qi et al. 2018). Furthermore, aggregating ESS types for stakeholders' elicitation purposes (Martínez-López et al., submitted) might lead to overestimation of ESS provision capacity and affect the final outcome of quantifying importance of specific habitats in relation to several ESS that are relevant for different stakeholder groups. This effect has to be considered in future research.

Through integrating approaches across aquatic ecosystems, better management alternatives along the river continuum can be highlighted, which support the development of sustainable EBM. Assessing and modelling causal links between biodiversity and ESS in aquatic realms (see Pletterbauer et al. 2016) and (Nogueira et al. 2016) (D4.1, D5.1) provides the baseline that subsequently allows decision makers to look into the future implications of different alternative management actions using external or management scenarios. The AQUACROSS case studies developed modelling approaches that allow forecasting potential changes of ecological and socio-economic systems or using scenarios to provide spatial designation of management areas.

From the project, and in concert with IPBES (2016), several future directions of research can be identified related to scenarios, including the consideration of (1) multiple spatial and temporal scales, (2) exploring multiple scenario types, and (3) interactions among different sectors. Considering multiple spatial scales is important and improves opportunities for capacity building, as different spatial scales (from local to national and regional) are operated based upon different drivers of change. Dealing with multiple temporal scales improves decision-making through providing both short- and long-term perspectives. Different phases of the policy cycle might be addressed by target-seeking multiple scenario types. Engaging different sectors and interactions among them contributes to capacity-building in the science-policy interface and prevents duplication of efforts of policy makers and scientists. The key drivers of increasing pressures on biodiversity such as agriculture or recreation activities in local areas are linked to important or emerging economic sectors. The AQUACROSS findings revealed that these economic sectors are in conflict with environmental policy goals. However, the latter promotes economic growth and supports these sectors via regulations without sufficient environmental safeguards (AQUACROSS Deliverable 2.3 forthcoming). This often results in little ambitious targets for biodiversity conservation in practice. One way forward is to restructure the frameworks in order to conserve biodiversity, while achieving a sustainable economic welfare (Deliverable 2.3).

The methods and spatial modelling approaches used in AUACROSS case studies are robust with high flexibility and transferability potentials. They can be up-scaled and are broadly applicable to a variety of aquatic realms (i.e., freshwater, coastal and marine) in any region of interest with comparable management challenges. Further applications to be developed and tested include, but are not limited, (1) to compare effects of e.g. management actions on different aspects of biodiversity, incl. species, genes, habitats/ecosystems, (2) to use models to prioritise policy actions, particularly in case of conflicting objectives, and (3) to estimate contributions of individual actions to global biodiversity targets.

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